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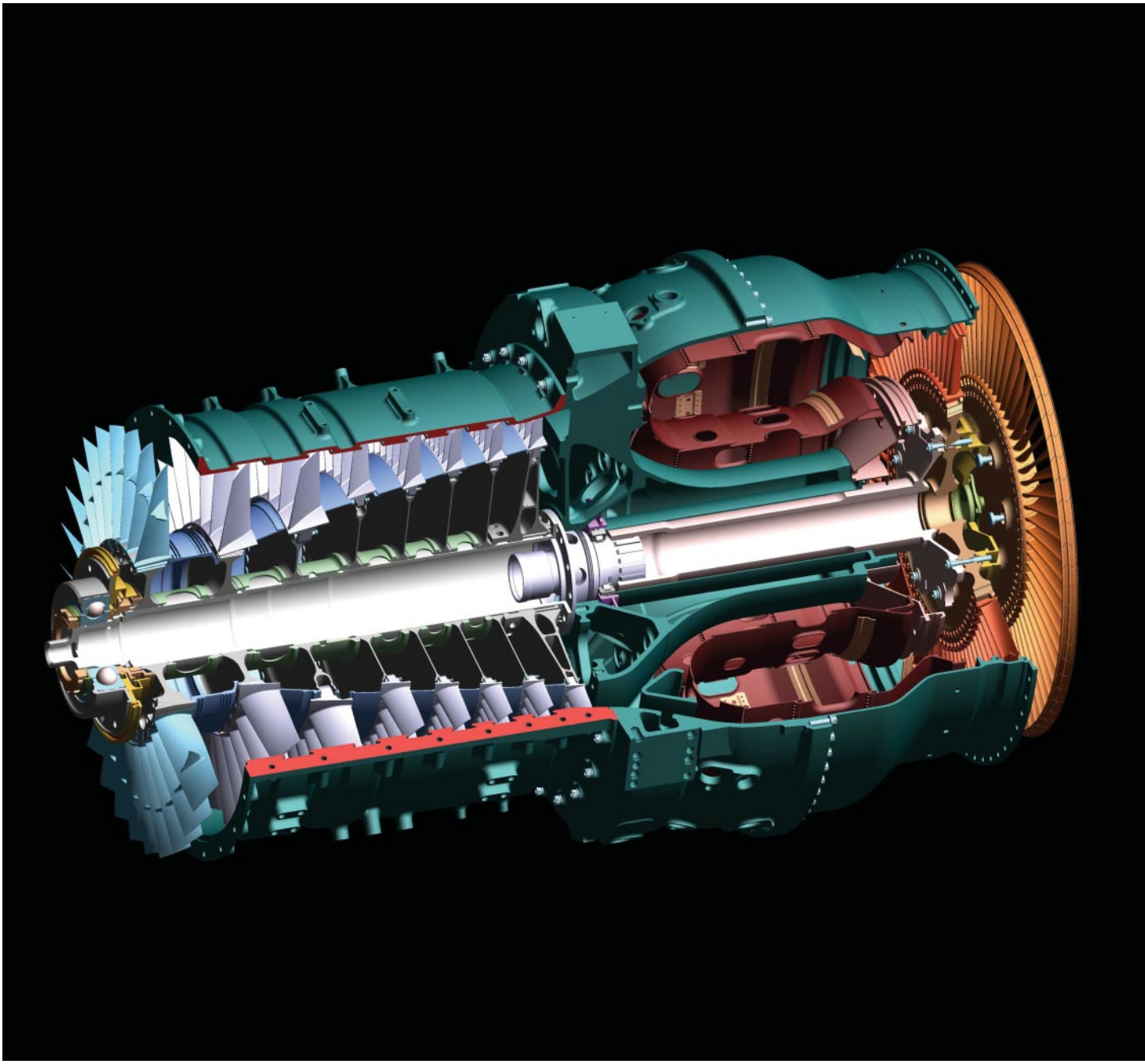
Best Practices for Implementing Digital Simulation and Analysis: *Five Lessons from Savvy Aircraft Engine Program Managers*



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Danvers, MA 01923-3630 USA

Tel. 978.774.1102
Fax 978.774.4841

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Best Practices for Implementing Digital Simulation and Analysis: *Five Lessons from Savvy Aircraft Engine Program Managers*

March 28, 2005

By Bruce Jenkins, Senior Analyst

Digital simulation and analysis is critical for aircraft engine manufacturers to meet program objectives on time and budget. The complexity, performance and efficiency demanded of today's engines simply can't be achieved any other way. How do they do it? We interviewed experts at industry leaders around the world to find out. What we discovered is that these companies are perhaps the world's most mature and sophisticated users of simulation and analysis. Use of the technology is pervasive throughout a program – it's brought to bear at the earliest stages of product development for whole-product performance characterization, then used intensively throughout product development and refinement into detail design. From hours of interviews we distilled five best practices that make this possible:

Manage people factors Garner executive sponsorship for new processes and technologies by tying simulation process improvement to corporate business objectives and to C-level initiatives and budgets such as Six Sigma, quality and efficiency programs. Leverage marketing/sales dependence on simulation-based characterizations of forthcoming product. Create receptiveness to new tools and processes among analysts and discipline by showing how better simulation process management and knowledge capture can help them be more productive.

Manage simulation data and processes Investigate tools and techniques that automate data exchange between analysis disciplines, and between CAD and CAE. Seek knowledge capture and simulation data management aids to increase efficiency and work throughput.

Rationalize the make/buy decision Use commercial software whenever it will suffice, but recognize the value or even indispensability of internally developed codes. Weigh the cost of maintaining in-house codes against moving to COTS solutions by identifying the true costs of change – not just software fees but re-integration, retraining, calibrating historical results against the new tool. Choose commercial software that is easy both to customize and to integrate with existing in-house and commercial codes.

Optimize simulation/test tradeoffs Leverage the relationship between digital simulation and physical test to get more value from both. Carry out as much design exploration and refinement as possible with simulation – drive test toward a role of final

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validation only. Use simulation/analysis early in a program, when designs have not been detailed to the point where test is feasible. Align analysis use with corporate initiatives to remove time and cost from product development. Use analysis results to optimize test design and execution.

Qualify and select solution providers To best support aircraft engines' multi-year development cycles and multi-decade product service lives, ground simulation/analysis purchase decisions in not only technical but also business criteria. Evaluate one set of solution providers on their ability to deliver the latest solver or mesher. Evaluate another set on their ability to help tie disparate tools together, streamline work processes, secure and shepherd corporate knowledge assets.

BUSINESS DRIVERS AND CONSTRAINTS

Aircraft engine manufacturers are among the industrial world's most advanced and sophisticated users of digital simulation and analysis. Why? One reason is that engines of today's complexity, performance and efficiency simply can't be developed any other way, at least not economically. But there's more to it than that.

> *"…new product cycle time [is the key business driver]. The customer wants new product in a certain time window…If you can develop product in a shorter amount of time, you also probably spend less money doing it – fewer labor hours, and less chance for requirements to change…" – Aircraft engine manufacturer A*

Developing a new aircraft engine is a massively complex undertaking that costs hundreds of millions of dollars and historically took as long as a decade. By helping reduce development costs and cycle time, simulation and analysis confers competitive advantage out of all proportion to its direct cost.

> *"…[management is] hearing from the design groups that, through the use of analysis tools, we have improved our products dramatically. How can we get 1% better in fuel burn? The advanced tools are showing us the way, and that gets their attention…" – Aircraft engine manufacturer A*

Simulation and analysis technology holds the key to competitive advantage in other ways as well. With the commercial air travel industry under intense cost pressure even as fuel prices soar, every increment of improved engine efficiency translates into significant savings for airlines, especially given the 20-year-plus service life of an engine. Meanwhile, defense markets have ever more complex and demanding requirements that challenge even the world's most simulation-savvy engineering organizations.

Against this background, we interviewed experts at industry leaders around the world to find out how they do it. What best practices have they developed for using simulation and analysis to achieve the business objectives that they and all manufacturers face – to boost product quality, performance, efficiency and innovation, shorten program schedules, improve engineering productivity, and reduce development costs? Not all wished to be identified, but we thank all participants for their valuable input to this report.

What we found was that use of simulation and analysis is pervasive throughout the product development process. In contrast to many industries, aircraft engine manufacturers bring this

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technology to bear at the earliest stages of product development for whole-product performance characterization, then continue using it throughout product development and refinement into detail design.

But maximizing the technology's business impact, we found, is more subtle than simply buying today's best point functionality and handing it off to the analyst or discipline lead. Instead, contemporary best practices focus on making more efficient use of existing resources – both software and engineering staff. No one we interviewed named software budgets as a constraint on product development's ability to contribute to corporate business objectives – all identified time and human resources as limiting factors. Pressures on new product cycle time, product performance, efficiency and total cost of ownership (TCO), and product development costs are driving companies to seek more value and output from their engineering resources.

> *"…we're trying to reduce product development time, improve quality – that is major – and reduce costs. [The greatest impact of] analysis tools is on product quality, followed closely by product development time. Both of those are followed by reduced costs of development…" – Aircraft engine manufacturer A*
>
> *"…unit cost is the single biggest driver…" – Dr. John Verdicchio, Analysis Specialist, Thermal Systems, Rolls-Royce*

To this end, initiatives to improve the efficiency and impact of simulation and analysis abound – Six Sigma, systems engineering, robust design, multidisciplinary optimization (MDO), Design for Six Sigma (DFSS) – and often enjoy C-level endorsement and funding. These initiatives are focused on process change, and on implementing technical enablers to overcome what one manager called the "entropy chain":

- Toolset integration
  - CAE-to-CAE
  - CAD-to-CAE
  - Commercial off-the-shelf (COTS) as well as internally developed tools
- Process automation
- Knowledge capture
- Simulation data management

In all this, we found that success depends on tight focus on five best-practice areas:

- Manage people factors
- Manage simulation data and processes
- Rationalize the make/buy decision
- Optimize simulation/test tradeoffs
- Qualify and select solution providers

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MANAGE PEOPLE FACTORS

Much of the challenge in optimizing use of simulation and analysis and maximizing its impact has to do with organizational considerations and people factors. Our research found that best practice focuses on two objectives:

- Garner executive sponsorship
- Create incentives for discipline leads, analysts, engineers to take ownership

Garner executive sponsorship

> *"…[our CEO] used the term CFD at the beginning of this year…[simulation and analysis] is no longer just a few engineers in the corner doing exotic stuff – it's really driving the business…" – Aircraft engine manufacturer A*

Why is executive sponsorship important? Because optimizing use of simulation and analysis is an investment. It requires budget. It requires process change. And progress is not always smooth, so when things hit a bump, it requires commitment to stay the course. If improvement initiatives cause short-term hits to productivity, C-level understanding and backing can be invaluable.

> *"…as we're striving for reducing development times, when they ask how we're going to get there, our answer is often that we're going to use our advanced tools, and thus not run 10 tests but get down to just one validation test…" – Aircraft engine manufacturer A*

Here's how to get it: Tie simulation process improvement to C-level initiatives – and budgets – such as Six Sigma, quality and efficiency programs.

> *"…in 3D aerodynamic design of compressors…use of simulation tools was key to achieving current levels of performance…" – Aircraft engine manufacturer A*

Another best practice is to leverage the dependence of the marketing and sales organizations on simulation/analysis characterizations of new products.

> *"...marketing [uses] simulations to decide what they can or can't quote as a product…" – Aircraft engine manufacturer A*

Create incentives for discipline leads, analysts, engineers to take ownership

> *"…aircraft engines is a very conservative business. Adopting new ideas and new technologies is quite a stretch – not new widgets in the engine, but new ways of doing things…It's getting people to change that's the challenge…" – Verdicchio, Rolls-Royce*

Of course, winning C-level buy-in is no guarantee of success. Alienating the head thermal analyst by forcing him or her to use a tool he/she doesn't like or trust is not the best way to get an engine out on schedule. How can managers create incentives for these individuals to take ownership of new processes and enabling technologies?

We found the answer often comes down to best practices for change management. What will motivate these individuals to change the way they work? One solution lies in the message

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that better simulation process management will allow more design alternatives to be explored – a goal well received by discipline leads.

Likewise, better capabilities for knowledge capture and process management can help analyst staff do more despite time and human-resource constraints – analyze a design more thoroughly, or analyze more designs in a given time. And making the up-front investments in simulation data management can make it much less vexing when analysts have to re-run or update analyses months or years later. Not to mention avoiding costly and embarrassing lapses by ensuring that design changes trigger re-analysis, analysts receive correct inputs from modified designs, and re-analysis results are properly disseminated and acted on.

Beyond this, we found that engineers and analysts involved in exploring "design spaces" – using methods such as robust design, multidisciplinary design optimization, design for Six Sigma – are often passionate about these new techniques for expanding the reach and impact of analysis tools.

MANAGE SIMULATION DATA AND PROCESSES

> *"…when someone runs an analysis, and a couple of years later wants to redo or update that analysis, we find it very hard to pull together all the data from that analysis. Or when something changes in the design, how do you make sure that analysis is re-run when the inputs are changed? It's an extension of PDM into all the associated analysis areas…" – Aircraft engine manufacturer A*

Best practice here is about better managing the flow of data between different simulation and analysis tools, and between simulation/analysis tools and CAD tools. It's also about being able to capture, archive and retrieve simulation models, input conditions and results, together with related assumptions and conclusions.

> *"…we need to be handling analysis data much better than we are…An initial look suggests the commercial tools have bits of what we need, but none of the vendors really yet understands our needs for managing simulation data for highly engineered products…" – Aircraft engine manufacturer A*

The principal constraints on getting more value from simulation and analysis are availability of trained professionals and time, not a shortage of software licenses or budget. We found that a key best practice being pursued to overcome these constraints is to tie these tools more closely together, using knowledge capture and simulation data management aids to increase work throughput. Objectives of these efforts are to:

- Automate data exchange between analysis disciplines, and between geometry modelers and mesh generators.

  "…even if [simulation and analysis tools] were free, we would still want to have tools at each phase that we could connect. We would worry about the entropy chain growing too dense…" – Aircraft engine manufacturer A

  "…If you want to roll out a new tool, you have to get people to do things differently, and also get the new tool to integrate into existing process or else work out a new process. Data translation is especially a big issue…" – Verdicchio, Rolls-Royce

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- Readily re-run or update analyses months or years later.
- Ensure that design changes trigger re-analysis; ensure analysts receive correct inputs from modified design; ensure re-analysis results feed back to design.
- Manage intellectual property (IP) exchange with offshore partners.

  "…tools having an ability to hide or encrypt some portions of the simulation activity and not others is important…" – Aircraft engine manufacturer A

  "…sometimes we'll contract out the engineering of pieces of the engine…in that work there are requirements to share the right version of analysis data…" – Verdicchio, Rolls-Royce

RATIONALIZE THE MAKE/BUY DECISION

Rationalizing the make/buy decision is all about managing the tradeoffs between commercial off-the-shelf (COTS) software and internally developed tools. Over the years, aircraft engine manufacturers have made substantial investments in developing proprietary simulation and analysis codes, understanding them, certifying them and getting comfortable with them. The key questions are: When and how should an organization move to an off-the-shelf solution? How can in-house codes best be integrated with COTS solutions? What should organizations do to keep their internally developed tools refreshed so they can take advantage of leaps in hardware performance?

"…[our weighting was] very heavily proprietary, historically, but it's shifting now…going from perhaps 10% COTS in the past, to 30% COTS today. It could end up 70% COTS in the next two or three years…" – Aircraft engine manufacturer A

"…probably 75% of our work is done using in-house code…" – Verdicchio, Rolls-Royce

We found there is no blanket answer at present. There is a general trend to use COTS whenever it will suffice, but also recognition of the value and in some cases the indispensability of internally developed codes.

"…[our stress analysis code] SC03 was originally written by two people in the company 18 years ago, and some of it is still better than what's available commercially…" – Verdicchio, Rolls-Royce

To weigh the cost of maintaining in-house codes against that of moving to COTS solutions, best practice is to identify the true costs of change. Beyond software license fees, these also include software re-integration, retraining, and the all-important calibration of historical analysis results against the answers produced by the new tool – that is, understanding and quantifying the algorithmic differences between the old tool and the new.

"…we clearly are trying to reduce the number of tools in use. Over the past ten years we've been successful in reducing the number of tools down to just a handful. Our major objective was to make it easy for designers to transition from one project to the next without having to learn a new set of tools…" – Aircraft engine manufacturer A

One best practice we uncovered is to standardize on one best-of-breed tool for each discipline, and use it in a standard way. Adopters report this simplifies data/process

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integration across the toolset, and lets engineers transition from one project to the next more readily. More, it lets companies build long-term relationships with a few key solution providers, increasing the attention paid and influence wielded. Finally, for tools with hundreds of users, it has the benefit of letting customers "buy in bulk."

> *"…there's a strong belief in best practices – that you should pick the best-practice tool and then use it in a standard way, instead of having every tool under the sun and using them all in different ways…" – Aircraft engine manufacturer A*

> *"…developing relations with a few vendors and being a significant part of their business gets you more attention from them…if you buy in bulk, you get bulk discounts…" – Aircraft engine manufacturer A*

Another best practice we uncovered is to define standard data exchange methods between tools.

> *"…typically we have many legacy codes…there's a historical database of results associated with the old tool. Not only does the new tool have to pay for itself, but there has to be a process change to ensure consistency in the changeover from old to new. When that turns positive, then it becomes worth moving to the commercial tool…" – Aircraft engine manufacturer A*

Thus, a value proposition to look for in COTS suppliers is not only quality codes, but also help in standardizing and rationalizing the contact points between applications, both in-house and COTS. Companies that do this well are getting high value from their systems, and finding relief from some of their human-resource constraints.

A related best practice is to seek help from solution providers with tools and methods to correlate results of in-house legacy codes with those of COTS solutions chosen to replace them.

> *"…if the commercial vendor (or we) can provide a validation process, then we can find a way to move…if we can understand the algorithmic differences between the old and new tool…mystery differences are not acceptable. Tools and auto-validation approaches that make it easier to attribute all changes in results between old and new tools make it easier to transition. Commercial vendors may provide a mechanism for setting up models that makes it easier to make those comparisons…" – Aircraft engine manufacturer A*

OPTIMIZE SIMULATION/TEST TRADEOFFS

The relationship between digital simulation and physical test can be used as a lever to drive change in how each is used in product development. We found that best-practice leaders are pursuing a goal of carrying out as much design exploration and refinement as possible with simulation/analysis, and driving physical test toward a role of final design validation only. While none feel this goal is fully practicable – for example, use of new materials not yet characterized in software will continue to require physical testing – all identified this as an ideal and an aim point.

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Key elements of this are to:

- Use simulation/analysis early in a program, when designs have not been detailed to the point where physical test is possible.

  "…you can simulate some situations, such as early in a program, when it's just not possible to test, but where you want to have some information so you can have impact on the program – make changes early in the design cycle, when it's very cheap to do so. Whereas later in the cycle, when test might uncover something, it's very expensive to make changes. Simulation lets you reduce the risk of finding big errors late…" – Aircraft engine manufacturer A

- Use simulation/analysis to drive the role of physical test away from discovery and refinement to final validation.

  "…we are increasing our ability to do more predictive work with software, in order to cut down the number of physical tests we carry out – finding more errors before physical test, designing right-first-time so the test does not come as a surprise…" – Verdicchio, Rolls-Royce

- Align simulation/analysis with corporate initiatives to drive time and cost out of product development.

  "…simulation and analysis is a way of reducing costs…though at some point you always have to test and do physical validation…" – Aircraft engine manufacturer A

  "…as we're striving for reduced development times, when [management] asks how we're going to get there, our answer is often that we're going to use our advanced [analysis] tools, and thus not run 10 tests but get down to just one validation test…analysis is critical, but the final check is always by test…" – Aircraft engine manufacturer A

QUALIFY AND SELECT SOLUTION PROVIDERS

For companies with long development cycles and product service lives, simulation/analysis purchase decisions need to be grounded in not only technical but also business criteria. Current best practice is to separate these two variables: evaluate one set of solution providers on their ability to deliver the latest solver or mesher, and evaluate another set on their ability to help tie disparate tools together, streamline work processes, secure and shepherd corporate knowledge assets.

Technical evaluation criteria

- Functionality of solvers
- Functionality of meshers, gridders, other tools for problem setup and results interpretation

Current best practice is to treat point solution providers somewhat opportunistically, evaluating technologies and adopting them as they become proven. The art is being able to incorporate these into the next project without betting the company's future – not a difficult challenge for companies that have made the right business evaluation.

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Business evaluation criteria

- Attractiveness as long-term partner
- Premium on stability and relationship

  "…developing relations with a few vendors and being a significant part of their business gets you more attention from them…" – Aircraft engine manufacturer A

  "…if [a competitor brings out a superior tool], we go back to our chosen vendor and say, 'What are you doing about it?'…" – Aircraft engine manufacturer A
- Commitment to providing help with process change, human/cultural issues
- Openness to integrating internally developed codes
- Commitment to providing:
  - Knowledge capture tools
  - Process automation tools
  - Simulation data management framework
- Software license models geared to make large multi-seat purchases attractive

  "…if you're talking about making it available to thousands of people, price is a big factor…" – Aircraft engine manufacturer A

In the aircraft engine industry, the overriding business criterion to look for in a solution provider is its ability to help a company increase its permeability and access to new technologies and code streams – without requiring prohibitive new investments in integration, support and personnel.

Another key business criterion is staying power. With aircraft engine service lifetimes at 20 years or more, the solution providers most likely to maintain business continuity on this time scale are the ones that best-practice leaders choose to partner with. Manufacturers in some respects bet the company on those relationships: these are the companies that help with the essentials of tool integration, process definition, data management, knowledge capture.

FIVE NEXT STEPS

To put these best practices into action, what can program managers and others do to get started?

Manage people factors ***Garner executive sponsorship –*** Find an appropriate time and venue to brief your CEO on the business impact of your organization's simulation and analysis competencies. Reinforce management awareness of how the technology contributes directly to board-level objectives. ***Create incentives for discipline leads, analysts, engineers to take ownership –*** Identify champions of advanced simulation and analysis within your organization. Enlist professionals who enjoy strong peer respect to lead process improvement initiatives. Cultivate corporate and public recognition of these champions.

Manage simulation data and processes For most organizations this is a new area where best practices are still being developed and validated. One way to start is to assemble

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a multidisciplinary team – include representatives from program management, the analysis and simulation groups, and the IT department – to audit current practices, identify gaps and bottlenecks, and develop detailed recommendations for improvement.

Rationalize the make/buy decision Make this an agenda item in planning and budgeting. Audit your current expenditures on both commercial software and internally developed tools, and revisit this allocation in each future budget cycle. Benchmark your organization against competitors.

Optimize simulation/test tradeoffs Audit three past projects – one highly successful, one typical, and one that could have gone better – to gauge whether superior management of the tradeoffs between simulation and test contributed to success. Use the audit to map existing processes for design refinement and validation, and identify opportunities for improvement,

Qualify and select solution providers In your organization's next procurement cycle, revisit your qualification and selection policies for simulation solutions to ensure they address your requirements not just for superior point functionality but also for simulation data management, tool integration and process optimization. Factor in solution-provider stability and longevity.

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Best Practices for Implementing Digital Simulation and Analysis in…

- ***Aerospace and Defense***
- ***Aircraft Engines***
- ***Automotive Powertrain***
- ***Consumer Electronics***
- ***Off-Highway***

Five reports that reveal how savvy program managers at the world's leading manufacturers are implementing digital simulation and analysis to create business value.

Digital simulation and analysis is key to making better products more quickly at lower cost. But maximizing the technology's business impact requires far more than just buying the right point functionality and handing it off to the analysis department. Spar Point interviewed program managers and discipline leads at top-ranked manufacturers around the world to find out how they do it – what best practices have they developed to use simulation and analysis to break through the critical business constraints their companies face today?

Each of these concise, industry-focused reports details five best-practice lessons from savvy program managers. Use this exclusive intelligence to benchmark your company against industry best practices – learn where you excel, where to improve and how. And discover key learnings in other industries that you can apply to your own efforts.

For complete product information and details on price and ordering, contact Tom Greaves, Spar Point Research, at email tom.greaves@sparllc.com or phone 978.774.1102.